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ABSTRACT

Longitudinal data on the auditory forward and backward digit span (FDS and BDS) subtests of the Wechsler Intelligence Scale for Children (WISC) were obtained at five age levels (between 6 and 13), in samples of white and black children. Factor analysis and analysis of variance of the data were conducted to test 5 hypotheses, related to Jensen's Level I - Level II theory: (1) FDS and BDS involve different components of cognitive ability; the former reflects rote learning and memory, the latter reflects complex cognitive processes; (2) BDS is more highly loaded on g, the general intelligence factor, than is FDS; (3) whites and blacks show a larger average difference in BDS than in FDS; (4) the difference between FDS and BDS decreases with increasing age (or mental maturity); and (5) whites and blacks of the same WISC mental age perform the same on both subtests. All of these hypotheses were supported, although results were not always consistent at every age level. (Author/CP)

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Forward and Backward Digit Span Interaction with Race and IQ: A Longitudinal Developmental Comparison

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ABSTRACT

Longitudinal data on forward and backward digit span (FDS and BDS) obtained at five age levels between 6 and 13 years in samples of white and black children, along with WISC data from four age levels, were used to test the following hypotheses relevant to Jensen's Level I-Level II theory of abilities: (a) FDS and BDS involve different factors of cognitive ability, (b) BDS is more g

loaded than FDS, (c) whites and blacks show a larger average difference in BDS than FDS, (d) the difference between FDS and BDS decreases with increasing age (or mental maturity), and (e) whites and blacks of the same WISC mental age do not differ in either FDS or BDS. All of these hypotheses are born out in general by the data, although not always consistently at every age level.

Forward and Backward Digit Span Interaction with Race and IQ: A Longitudinal Developmental Comparison

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The forward digit span (FDS) and backward digit span (BDS) subtests of the Wechsler Intelligence Scale for Children (WISC) appear to be culturally homogeneous tests. That is to say, it seems difficult to put forth a reasonable argument that performance on FDS should be differently affected by cultural factors than performance on BDS. This would surely seem to be true as compared with the contrast between, say, the Vocabulary and Block Design subtests of the WISC.

Despite the apparent formal similarity between the FDS and BDS tasks, there is now good evidence that they are actually quite different psychologically. FDS and BDS involve different components of mental ability. In terms of Jensen's two-level theory of mental abilities, FDS reflects predominantly Level I ability, i.e., rote learning and memory. BDS, in contrast, requires considerably greater transformation of the stimulus input prior to recall, and this involves Level II ability (i.e., complex cognitive processing) to a greater degree that does FDS. The idea that FDS and BDS involve different abilities is suggested by the findings that individual differences in the two tasks are not nearly as highly correlated as their reliabilities would permit, and FDS and BDS usually have their largest loadings on different factors when they are factor analyzed among a variety of other cognitive tests. Theoretically we should expect that when a general factor or g is extracted from a battery of complex cognitive tests including FDS and BDS, the BDS should have a larger g loading than FDS.

There is already some evidence for this. Meeker (Note 2) factor analyzed a battery of 25 tests given to 90 ninth-grade boys, using an orthogonal (varimax) rotation, and identified two distinct factors for auditory forward and backward span for both digits and words. Factor scores on the backward span factor correlated more than twice as much

with five tests of scholastic achievement as did factor scores on the forward span factor, with mean correlations of 0.59 versus 0.24, respectively.

Hall and Kleinke (Note 1), using groups of middle- and lower-class whites and lower-class blacks in the second grade, found that within each social class BDS was more highly correlated than FDS with scores on Raven's Colored Progressive Matrices, a good test of g or Level II ability. There was no difference between the means of lower-class whites and lower-class blacks on FDS (4.80 vs. 4.80), but these groups differed significantly on BDS (3.09 vs. 2.20). (The means of FDS and BDS for middle-class whites were 5.28 and 3.25, respectively.)

Very similar findings were reported by Jensen and Figueroa (1975) for large representative samples of white and black school children in California. BDS showed significantly higher correlation than FDS with the WISC-R Full Scale IQ, and the white-black mean difference (in standard deviation units) was more than twice as large for BDS as for FDS. This racial difference between FDS and BDS remained essentially unchanged when socioeconomic status was controlled. In both racial groups, the difference between FDS and BDS significantly decreases with increasing age of the subjects, over the age range from 5 to 12 years. All these

findings--the differential correlation of FDS and BDS with IQ, the white-black interaction with FDS-BDS, and the decrease in FDS-BDS with increasing mental maturity--were all predicted from Jensen's formulation of the Level I-Level II theory of abilities (see Jensen & Figueroa, 1975).

The present study examines these phenomena involving FDS and BDS in a set of longitudinal data on the WISC, spanning the age range from about 6 to 13 years, in large samples of white and black school children. These rare longitudinal data were not originally collected (by the second author) for this purpose, but they became of highly relevant interest when we hypothesized that the white-black interaction with FDS-BDS is due essentially to a difference in developmental rates in Level II ability. The present longitudinal data permit an examination of this hypothesis.

Method

Subjects

Longitudinal data on auditory forward and backward digit span were obtained by the second author on groups of white and black children at five different age levels, as shown in Table 1. At each age level the ages of the white

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Insert Table 1 about here

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and black groups scarcely differ in means or standard deviations. As can be seen, there was some attrition of the sample size (N) over the approximately seven years since the original testing. However, we find no systematic bias in this attrition with respect to the variables under investigation.

At the first testing, there were nearly equal numbers [(N/2)±1] of boys and girls within each racial group.

The Ss were selected from two schools in each of three counties in Georgia, representing small rural (pop. 20,000), medium (pop. 45,000), and large industrial (pop. 88,000) communities. The first testing was done in July and August, 1961.

At the first age level the entire WISC was individually administered to every subject by qualified psychometrists according to the standard procedures specified in the WISC Manual (Wechsler, 1949). At the second, third, and fourth age levels the same procedure was used for every available subject who was in the original group. Forward and backward digit span are part of the WISC battery. At the last testing, in the 7th grade, it was not feasible to administer the entire WISC. Only the forward and backward digit span tests

Table 1

Chronological Age (in Years) of Longitudinal Samples at Each Grade Level

	White			Black		
Grade	N	Mean	SD	N	Mean	SD
Pre	163	6.13	0.31	111	6.10	0.33
1	153	6.98	0.28	103	7.01	0.33
3	127	8.84	0.30	93	8.85	0.33
5	128	10.85	0.29	97	10.80	0.32
7	112	12.85	0.29	97	12.89	0.34

were used, and these were group administered in the classroom. The examiner read each series of digits aloud in the standard manner, and then the Ss wrote their responses on a specially prepared answer sheet instead of responding orally, as in the individually administered WISC. We are not sure how much the written form of response may differ from oral response in the digit span test, but it seemed to us preferable to include these data in our analysis, keeping in mind the difference in administration, rather than to exclude them. Unfortunately, WISC IQs could not be obtained in the last testing.

Results

WISC IQ

The means and standard deviations of the WISC Verbal, Performance, and Full Scale IQs at each age level are shown in Table 2. Both racial samples score somewhat above the

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Insert Table 2 about here

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national average for their respective populations. In terms of the standard deviation of 15 for Full Scale IQ in the national standardization samples, the present whit and black means differ by 1.23σ. The two groups have quite similar SDs, which are both significantly smaller than the

Table 2

WISC Verbal, Performance, and Full Scale IQs of White and Black Samples at Each Grade Level

	White						Black					
	Verbal		Performance		Full Scale		Verbal		Performance		Full Scale	
Grade	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
P	104.0	13.6	101.3	13.8	103.0	13.4	90.0	12.1	80.9	12.2	84.2	11.8
1	109.5	11.8	108.9	12.1	110.1	11.7	95.5	12.2	90.7	12.2	92.5	[illegible].6
3	106.8	11.1	107.3	12.4	107.7	11.1	91.5	10.6	91.1	12.5	90.5	10.8
5	109.5	13.1	110.3	14.2	110.9	12.7	91.3	12.7	90.7	14.4	90.2	12.8
Mean	107.3	12.5	106.7	13.1	107.7	12.3	92.1	11.9	88.1	12.8	89.2	11.8

normative SD of 15.

Factor Analysis of Forward and Backward Digit Span

The 10x10 matrix of intercorrelations of FDS and BDS at each of five age levels, separately for whites and blacks, was subjected to a principal components analysis and orthogonal rotation of the components with eigenvalues greater than 1 to approximate a criterion (varimax) of simple structure. The question of primary interest is whether different factors emerge in terms of age differences or in terms of a difference between FDS and BDS. The results are fairly clear-cut. In both racial groups, only two rotated factors are interpretable. (A third factor with an eigenvalue > 1 emerged but is significantly loaded only on FDS at grade 8 in both groups.) The first two rotated factors, shown in Table 3, represent FDS and BDS factors, respectively, in both racial groups. But there is a couple of anomalies:

Insert Table 3 about here

(a) At the youngest age level for whites, both forward and backward digit span (FP and BP) have their largest loadings on the first factor, which suggests that in the white group at this age (6 years) the ability components involved in FDS and BDS are not yet differentiated; and (b) FDS at grade 7 has no appreciable loading on either of the two factors for

Table 3

Varimax Rotation of Principal Components of Forward and Backward Digit Span at Five Grade Levels

	White		Black	
Variable	I	II	I	II
F_P	.67	.06	.66	.45
F_1	.80	.04	.59	.45
F_3	.68	.11	.77	.17
F_5	.60	.30	.82	.01
F_8	.12	-.02	.08	.07
B_P	.72	.34	.06	.70
B_1	.11	.78	.37	.53
B_3	.03	.65	.10	.63
B_5	.39	.30	.45	.58
B_8	.20	.66	.16	.62
% Variance	26.5	17.8	24.3	23.3

either whites or blacks, suggesting that at grade 7 the FDS test is somehow different from the rest of the FDS tests, possibly because it required written rather than oral response; yet BDS at grade 7, which also required written response, is factorially quite in line with BDS at all the other ages. In general, the factor structure indicates that FDS and BDS involve different abilities or cognitive processes and that individual differences in those abilities are fairly consistent developmentally over the age range tested, i.e., about 6 to 13 years. The correlations of either FDS or BDS from one age to the next are higher than the correlations between FDS and BDS at any given age.

Loadings of FDS and BDS on g

It has been hypothesized that BDS, since it requires more mental transformation than does FDS, is more highly loaded on Level II ability or g (general intelligence) than is FDS. To examine this, we have extracted the first principal component of the 12 subtests of the WISC, including FDS and BDS, spearately in the two racial groups at each age for which complete WISC data were obtained. The first principal component is the general factor of the WISC battery; it best represents the largest source of variance which is common to all of the subtests. Factor scores derived from the subtest loadings on the first principal component have a

larger variance than any other linear composite of the subtest scores. In the case of the WISC, the first principal component is probably the best estimate of Spearman's g, the general intelligence factor.

Table 4 shows the loadings of FDS and BDS on the first principal component of the WISC. The significance of the

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Insert Table 4 about here

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difference between the loadings of FDS and BDS was tested by Hotelling's t (Walker & Lev, 1953, pp. 256-257). Six of the eight pairs of loadings show differences in the theoretically predicted direction, i.e., BDS>FDS, and of these three are statistically significant. In terms of theoretical expectation, the results appear anomalous for whites in grades 1 and 3, with FDS showing the larger loadings on the first principal component. In the black sample, however, the results are consistently and significantly in accord with theory. Since one would not expect a large true difference in the g loadings of FDS and BDS, the sizes and even the direction of the differences in their g loadings in any particular sample may quite easily be swamped by sampling and measurement errors.

Table 4

Loadings of FDS and BDS on First Principal Component of Twelve WISC Subscales

	White		Black	
Grade	FDS	BDS	FDS	BDS
P	.49	.73**	.45	.62*
1	.55	.33**	.51	.63
3	.33	.14	.45	.51
5	.41	.47	.33	.68**
Mean	.45	.46	.44	.62*

* Difference between FDS and BDS loadings significant at $p<.05$, 2-tailed test.

** Difference between FDS and BDS loadings significant at $p<.01$, 2-tailed test.

Race Interaction with FDS-BDS

The hypothesis that the average white-black difference in cognitive ability essentially involves Level II (transformational) processes more than Level I (associational) processes led to the prediction that whites and blacks would show a greater average difference in performance on backward than on forward digit span tests, and this prediction is born out in previous studies (Hall & Kleinke, Note 1; Jensen & Figueroa, 1975).

We may now examine this hypothesis longitudinally, by plotting mean FDS and BDS, separately for whites and blacks, as a function of chronological age, as shown in Figure 1.

Insert Figure 1 about here

Analysis of variance was done at each of the five age levels to test the significance of the interaction of digit span (FDS-BDS) and race (white-black). (At all age levels the main effects of race and span [forward vs. backward] are significant beyond the .001 level, except at the final testing, where the race main effect is significant at $p=.016$.) The interaction of race x span is significant ($p<.005$) at each of the three ages indicated by asterisks in Figure 1. At ages 9 and 11 there is negligible and nonsignificant interaction ($F<1$). The interaction of race x span over all

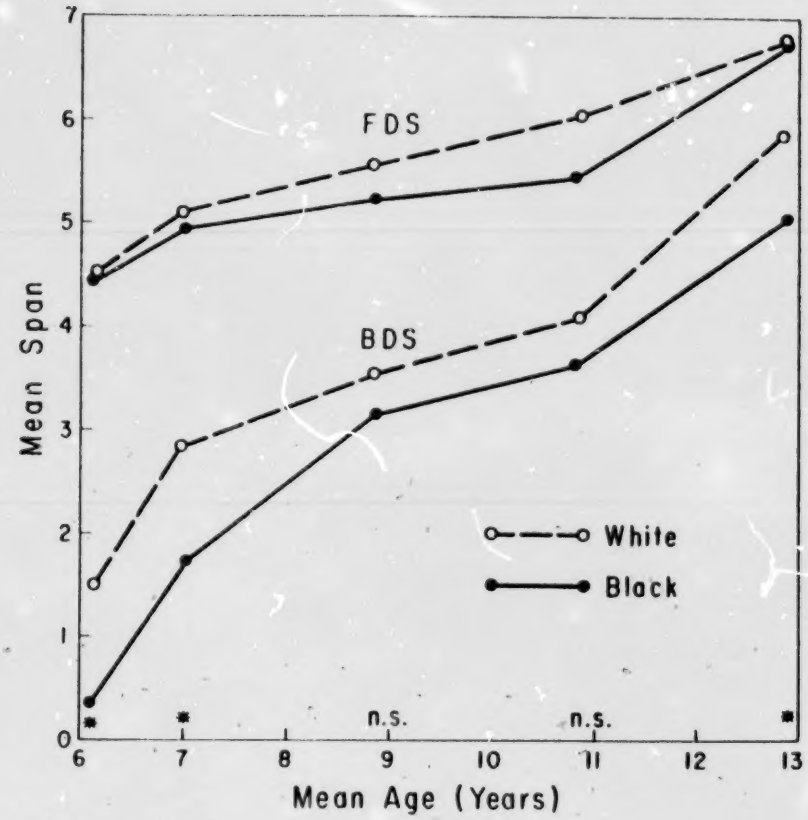

Figure 1. Mean forward (FDS) and backward (BDS) digit span of white and black children plotted as a function of their chronological age (longitudinal data). Asterisks indicate the ages at which analysis of variance shows the interaction of race (white-black) x span (forward-backward) to be significant (in all instances $p < .005$); n.s signifies a nonsignificant interaction.

ages combined is significant beyond the .001 level. The overall white-black mean difference on FDS is 0.24; on BDS, 0.00. Thus the theoretical expectation is on the whole born out. Why the predicted interaction failed to appear at ages 9 and 11 is unknown, and theoretical speculation about it would seem idle without replication of what, at this point, seems an anomaly.

Age Trend in FDS-BDS Differences

From the differing hypothesized forms of the developmental growth curves of Level I and Level II abilities between about 5 and 13 years of age, Jensen and Figueroa (1975, p.883) predicted that the difference between FDS and BDS should decrease with age (regardless of race). That was found to be the case over different groups of subjects ranging in age from about 5 to 12 years. The present longitudinal data for the combined racial groups show substantially the same thing: the difference between FDS and BDS decreases regularly from the first to the last age level, in each racial group. The linear correlation between the five mean FDS-BDS differences and mean chronological age is -0.94 in the combined racial groups (r=-0.94 for whites and -0.89 for blacks). The linear regression b=-0.28 of the FDS-BDS difference on age (in the combined groups) indicates that the FDS-BDS difference decreases by an average of 0.28

digits per year in the age range from about 6 to 13 years. These trends can be seen graphically in Figures 2.

Insert Figure 2 about here

Racial Comparison by Mental Age

As we have seen above, when FDS and BDS are plotted as a function of chronological age (Figure 1), the white and black groups differ on both spans, but they differ overall more on backward than on forward span. We also noted a developmental trend for the difference between FDS and BDS to decrease as a function of chronological age in both racial groups (Figure 2). Both findings are generally consistent with the formulation of the Level I-Level II theory, which is spelled out in detail elsewhere (Jensen & Figueroa, 1975).

A new hypothesis to be considered in relation to the levels theory is that the interaction of race with Level I-Level II performance is a manifestation of a difference in developmental rates, with the blacks, on the average, lagging in rate of cognitive development, when compared with whites. If this is true, whites and blacks who are at the same stage of cognitive development should show no difference in forward and backward digit span. To test this

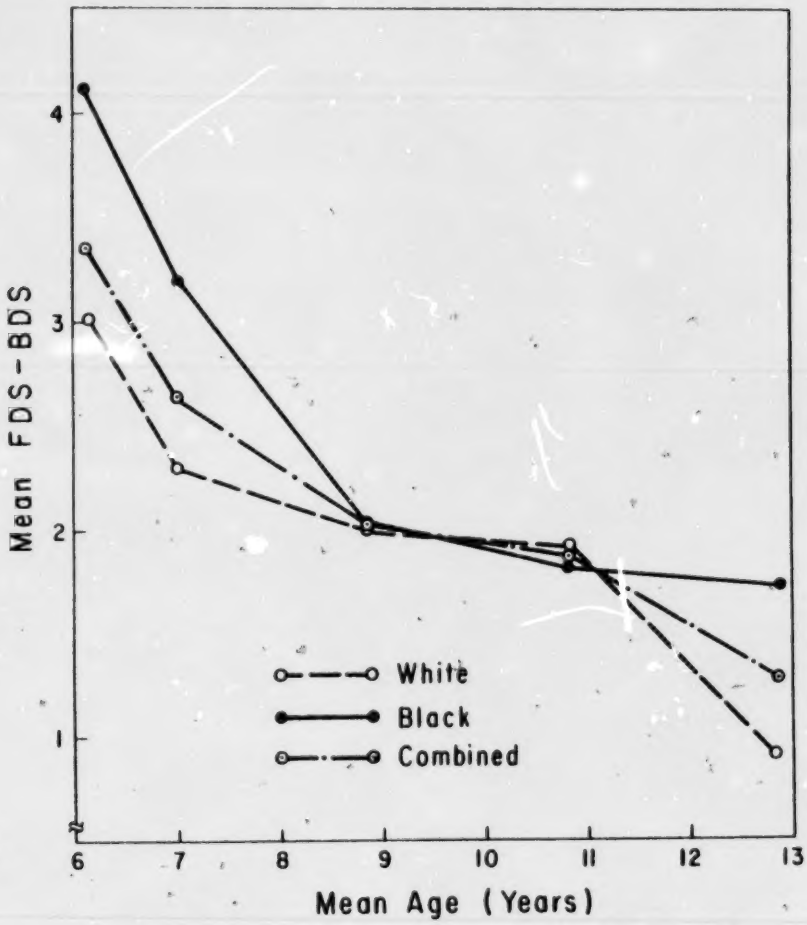

Figure 2. The mean difference between forward and backward digit span (FDS-BDS), as a function of chronological age in white, black, and combined samples.

hypothesis, we have plotted FDS and BDS as a function of mean mental age based on the total WISC. The WISC mental age is our index of cognitive developmental status. The hypothesis predicts that whites and blacks of the same developmental status should show no differences in either forward or backward digit span, and hence no interaction of race x FDS-BDS.

The results of plotting FDS and BDS as a function of mental age for each race are shown in Figure 3. It is

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Insert Figure 3 about here

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apparent that the white and black plots closely coincide, except for the last test in the series. But these results of the last digit span tests are probably questionable (as indicated by the ?s in Figure 3) in the present context, and afford the weakest test of the theory, for two reasons: (a) the last test differed from all the preceding tests by requiring written instead of oral response, and (b) since the full WISC was not administered at the last testing, we could merely make an estimate of the mean mental ages for the last age level. (This was done by averaging the Full Scale WISC IQs from all four previous tests and obtaining MA as the product of the chronological age x IQ/100.) ANOVA reveals that at no point in Figure 3 is there a significant

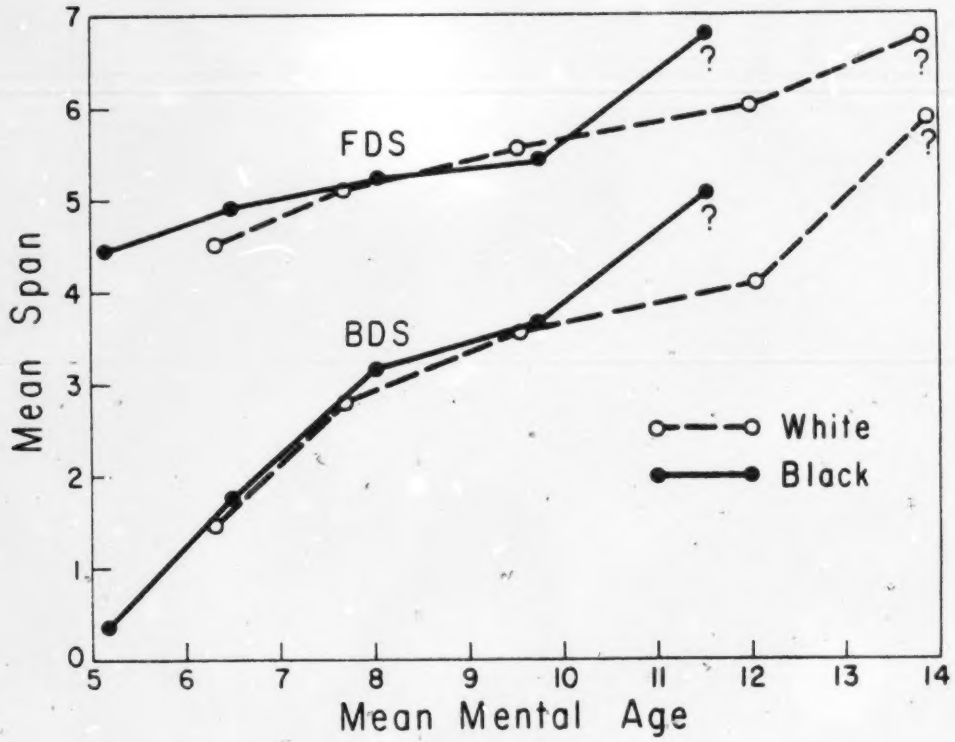

Figure 3. Mean forward (FDS) and bakcward (BDS) digit span of white and black children plotted as a function of their WISC mental ages. The question mark (?) indicates data points for which the mental age was not obtained directly (since the WISC was not administered at that age) but could only be estimated from the WISC IQs actually obtained at the four previous age levels (see text).

race x FDS-BDS interaction, and only at the last mental age (between MA11 and MA12) is the main effect of race significant ($p<.01$). Thus, with the exception of the rather questionable comparability of the last data points (indicated by ? in Figure 3), the hypothesis is mainly born out: whites and blacks matched on mental age do not differ in either forward or backward digit span.

Discussion

Five hypotheses relevant to Jensen's Level I-Level II theory of abilities are supported in general by these unique longitudinal data on white and black children tested at five intervals between the ages of 6 and 13 years: (a) forward and backward digit span involve different components of cognitive ability which are relatively stable throughout this age range, as indicated by the emergence of two factors clearly identifiable as forward and backward span factors from the factor analyis (i.e., varimax rotated principal components) of all the FDS and BDS scores across ages; (b) BDS is more highly loaded on *g*, the general intelligence factor (identified with Level II ability), than is FDS (identified with Level I ability), when these tests are included in a principal components analysis of all the WISC subtests and the first principal component is interpreted as *g*; (c) the overall mean white-black difference is about

three times greater (in standard deviation units) on BDS than on FDS; (d) the difference between FDS and BDS decreases as a function of age (or increasing mental maturity) in both racial groups; (e) white and black children of the same WISC mental age perform the same on both FDS and BDS, suggesting that the interaction of race x FDS-BDS found for white and black children of the same chronological age may be interpreted as a manifestation of a difference in average rates of cognitive development.

The present data, however, cannot answer the question as to the cause of the racial difference in developmental rates. But if the cause is cultural, it would seem to us a remarkable coincidence that a cultural difference between the racial groups should so closely simulate developmental differences <u>within</u> each racial group. The hypothesis suggested here should give rise to further studies based on a variety of other tests which index stages of cognitive development. We would predict, in accord with the present findings, that the average differences between representative samples of age-matched white and black children on a variety of tests of cognitive development will quantitatively and qualitatively closely parallel cognitive developmental differences among children from the same racial, socioeconomic, and cultural background, and even among older and younger full siblings reared together.

It was noted that not all of the hypotheses are fully born out by the data at every age level, and there would seem to be some methodological lesson to be learned from the observation that certain hypotheses would not have found any support at all if the study had been limited to one certain age level of these particular samples of white and black children. Perturbations due to uncontrolled and unknown factors, generally termed sampling and measurement errors, can easily obscure the appearance of a not very robust phenomenon. In the present case, the contrast between forward and backward digit span is not a very robust phenomenon as a method for testing theoretical predictions, especially where samples sizes are not unusually large. The method yielded highly unequivocal results, for example, in the study by Jensen and Figueroa (1975), with its much larger samples, thereby reducing sampling error. The attraction of the FDS-BDS paradigm in this theoretical context is, of course, that the two tasks, as mental tests, are so simple and so similar: their content (or "fundaments," to use Spearman's term) is virtually identical, and they differ only in the complexity of the cognitive processes (transformations) that the subject must apply to them. In this sense, the FDS-BDS paradigm provides a conceptually rather clear-cut test of the Level I-Level II (or association vs. transformation) formulation, albeit at the expense of not

very robust measurements. Factorially, forward and backward span differ only slightly (though the difference is theoretically important); and the digit span tests of the WISC have relatively poor reliability and stability due ot their brevity. The digit span paradigm cannot be recommended for small-sample studies without repeated measurements. However, in the few studies in which it has been used so far, we believe it has yielded some interesting insights into the nature of the still inadequately understood difference between whites and blacks in a variety of tests of cognitive ability and scholastic performance.

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